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PRINCIPLES OF INSTRUCTION FOR SUCCESSFUL ASSEMBLY AND
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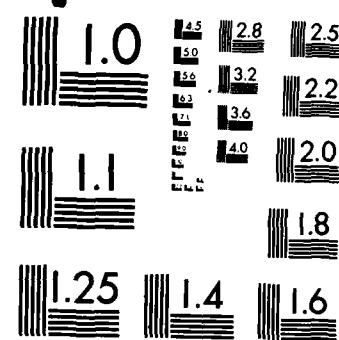
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FINAL REPORT

Principles of Instruction for Successful Assembly and Repair

Report Period: November 1, 1983 - November 31, 1984

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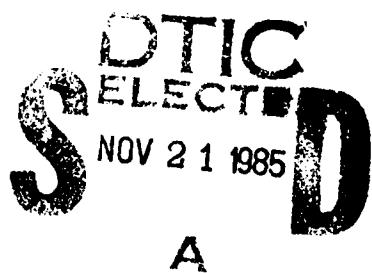
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In this one-year project the aim was to continue the previous three years' research on designing multimedia instructions for procedures that people could use and learn from them more easily. There were both theoretical and practical aspects to the work. We viewed the conceptual structure of a task as a (hierarchical) tree (later a directed acyclic graph) with nodes representing information from different modalities (motoric, visual, and linguistic). This theoretical viewpoint directed the experimental work. We will give below an overview of the studies, including progress and results, and several principles for instructional design which came from the experiments.

The overview will be preceded by a short summary, stating the five main studies, the total number of subject hours run, stimulus materials used, and computer programming done. At the end are listed technical reports, conference papers, and publications.

>Main Studies:

- (A) Transforming a task's tree structure to lessen short term memory load in instructions,
- (B) Developing generic and functional terminology,
- (C) Theoretical hypotheses about what narration in dual media presentations should consist of,
- (D) Transfer of learning in assembly tasks, and
- (E) Empirical investigation of adequacy of knowledge representation for repair in a computerized tutor.

Number of subject hours run: 1200

Main videotapes used as stimulus material; The Lift (2 versions, both prepared by Bud Leonard, a television director from Academic Media Services at the University of Colorado).

Main assembly kits used; ^{and} Fischer Technik 50 and Capsela 1000. Also, Eveready flashlights were used for repair tasks.

Supporting programs: Finite State Grammar for Terminology, M. Kent, 1983; Computer Techniques for Cluster Analysis (extended), R.M. Perry, 1984.

Overview of Studies

- A. Transforming a task's tree structure to lessen short term memory load in instructions.

In previous work we showed that videotape instructions based on a "majority" conceptualization of an object (its breakdown into subassemblies, subsubassemblies, etc.) yield better performance than those based on a "minority" conceptualization. In the videotapes used, the conceptualizations (trees) were traversed in a top-down, breadth-first manner. For example, the

entire object was shown; then all its subassemblies were shown and assembled into the object; then each subassembly's subsubassemblies were shown and assembled, etc. Our first major question in this research was whether, using the same majority conceptualization, a videotape could be prepared whose shot sequencing and content were even better.

We can transform mathematically any tree T , which represents a conceptualization, into a conceptualization T' . T' , when traversed, presents a cued sequence of actions. (The transformation involves editing the original concept by changing the relations of subconcepts.)

The key difference between traversing T and traversing T' is that, in T' , anytime a new subassembly is introduced, it is directly visually preceded by something (a piece or a subassembly) which is a part of it. This hypothetically means that what is physically present immediately before cues the concept represented by the assembly. Another difference between the videotapes showing T and T' is that, in T' , two cameras are used simultaneously. One camera shows (on the right of the image) the goal or subassembly one is working toward, i.e., what should be kept in mind. The other camera shows (on the left) hands getting parts and putting together the subassembly. In T , only one camera was used, with no goal shown.

We have counted the number of concepts which the central processor (in our theoretical framework) must keep "on hold" during traversal of T versus T' . We can show that resource requirements are considerably less for T' than for T .

Two groups were shown videotapes, based on T and T' respectively, displaying assembly of the eighty-piece object (the lift) pictured in Figure 1. (The names given to subassemblies are shown in Figure 2. Trees T and T' for the lift are shown in Figure 3.) Afterwards subjects built the lift from memory. Both structural and functional measures were made on their memorial lifts. For structure, the number of correct connections was counted. For function, whether or not the lift worked was assessed. Table 1 gives the results.

A 2×2 (T' vs T videotape; male vs female) between subjects ANOVA on the number of correct connections showed no main effect of either videotape or gender, but an interaction of videotape \times gender. Females (novices in their own estimation) perform significantly better when instructed by T' , and for the first time in any assembly task in this research, their performance equals that of males.

The experimental result yields a very precise and easy-to-follow guideline for visual presentation of instructional material which significantly helps novices.

B. Developing generic and functional terminology.

A second major question, again derived from our earlier work, was how functionality (the way pieces in an assembly kit are used) influences the names a person gives to the pieces. We previously developed a methodological schema for getting good names for parts. Basically, the names were generated

by people and the "majority" names were chosen. They could be iteratively improved, based on matching and recall. We used a part of the same method in this new research.

Here we were concerned with two kinds of names: generic vs functional. An example of a generic name is 1/2 x 5 x 8" cedar board. Examples of functional names are shingle, cutting board, lid for box, and piece of firewood. Often generic and functional names will be identical, typically if a given object has only one use, for example, a hammer.

We needed an operational definition to decide if a name was generic or functional. The experimental schema was easy:

(1) Show the subject an object "out of context." The subject generates a name for it. This is a generic name.

(2) The subject uses the object for some specific purpose. While doing so, the subject generates a name for it. This is a functional name.

In the experiment, we were interested in the transfer of the functional name, generated at the time of use, into the generic name, generated later, out of context. We had subjects use an object for a specific purpose. Then later, "out of context," subjects were asked to name it. Names generated by such subjects could be compared with names by people who never used the object for that purpose, to measure how frequently or strongly functional names become (are generated as) generic names. There were five groups of subjects:

(1)	(2)	(3)	(4)	(5)
Name 46 pieces of Capsela kit out of context.	Build objects A1 and A2. Name 46 pieces out of context.	Build objects B1, B2, and B3. Name 46 pieces out of context.	Build A1 and A2. Wait 48 hours. Build B1, B2 and B3. Name 46 pieces out of context.	Build B1, B2, and B3 Wait 48 hours. Build A1 and A2. Name 46 pieces out of context.

The analysis was done using software written by Marty Kent (1983). It selects the most commonly generated names. There was a strong shift from functional to generic names, i.e., people used functional names as generic names. For 26% of the names (12 of 46) the majority (or plurality) name was different for group 1 versus groups 2, 3, 4, and 5. Table 2 gives some examples.

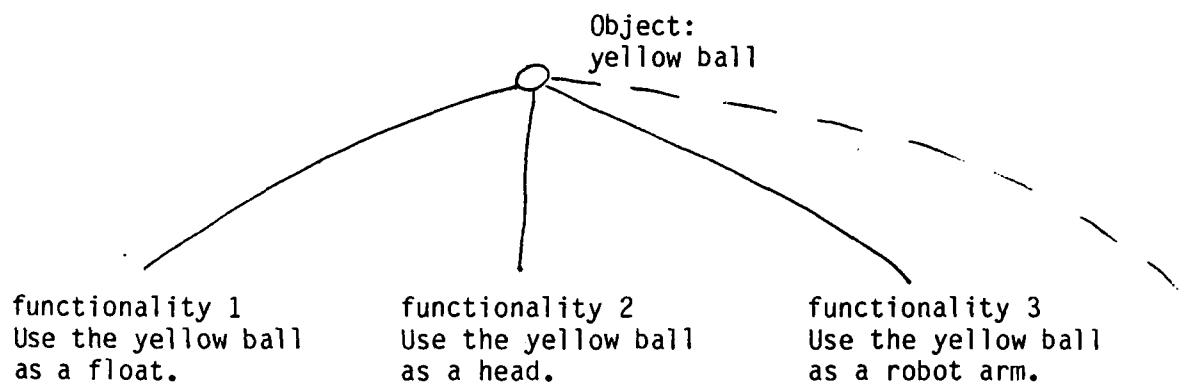
There was evidence of lateral transfer. Within a given group, functional names were used for objects similar to ones used in the actual construction. For example, group 3 never used piece #13 as a propeller, but they did use piece #12 as a propeller. (See Table 2.)

Many names (plurality) did not change at all. In many situations, this was expected, because, if in the task the functional name coincided with the generic, the subject would not switch the name.

When subjects used a piece for two different purposes, separated by a 48-hour delay, the most recent purpose determined the name.

We think that these naming results are interesting not just as a linguistic observation, but because they have some predictive value. The names subjects use indicate how they conceptualize an object. We could expect negative transfer of learning when subjects are given a task in which objects have to be used functionally in different ways. For example, suppose an object's name (because of use) becomes "float," and now it is used as a propeller. We expect that subjects would make errors, or not spot errors of use.

Our general hypothesis for part names, for good transfer, is: construct names based on generic concepts, and extend them for specific uses. Here is an example of a structure of a concept we want subjects to build:



C. Theoretical hypotheses about what the narration should consist of in dual media assembly instructions.

Below is a list of observations and suggestions derived from our theoretical framework. They were used in designing the narration for our T' assembly videotape.

1. Instructions supposedly build concepts, the relation of subconcepts, and the relation of links. They also build the identity relation: when an object is shown a second time, it needs to be identified as the same as before. (See 4 below.)
2. Narration is secondary to visuals. This means the narration should not form an independent text. Thus, as little grammar as possible should be used. The narration should be limited to the concepts visually presented, with no extraneous material.
3. The role of narration should be to direct attention for building the concept. Narration should not precede, but be in synchrony with or later than, the visuals (Baggett, 1984).
4. In establishing the identity relation, only names for subassemblies that have been shown visually should be used. When there is a visual orientation change, establishing identity verbally is especially important.

5. Early narration should be limited. Narration should become richer as the end is approached.

6. Via motion, the motoric component is visually shown. The proper verbal comment is to describe the action (using the imperative) and then the result, to parallel the visual: "Press the wheel with your thumb to snap it on the axle."

7. Numbers should be used freely. This helps form the concept of a group of pieces.

D. Transfer of learning in assembly tasks.

The fourth area of study was transfer of learning. The basic question was whether, when a person builds two objects A and B, with a common substructure C, the conceptualization evidenced in C as a part of A (built first) will also be present as a part of B (built second). If so, we will say there has been transfer of learning (transfer of conceptualization). (In our earlier work, we gave a method to derive a person's hypothetical conceptualization of an object he is building, based on the order in which the person uses the pieces in building.)

There were 3 groups of subjects each containing 12 males and 12 females:

<u>Group</u>	<u>Task</u>
1	Build C only (a substructure common to A and B)
2	Build A first; build B second.
3	Build B first; build A second.

"A" was a model helicopter with 54 pieces and 58 connections; "B" was an eggbeater with 60 pieces and 70 connections. Both were made from the Fischer-Technik 50 assembly kit.

We did the following data analysis. In all groups, we focussed on the conceptualization of C. There were three analyses:

- (1) Look at conceptualization of the whole object (helicopter or eggbeater), and then restrict it to C.
- (2) From the original order of selection, we can strike out all pieces not belonging to C, and find the conceptualization of C alone, in one of 2 ways:
 - (a) renumber the selections in C, so that they range from 1 to 24, the number of pieces in C.
 - (b) do not renumber the selections in C, so that the range is greater than 1 to 24.

At the close of this project, the analysis, done with software written by R.M. Perry, was in progress. We report a preliminary analysis, found after the end of the project. We will say more transfer of learning has occurred in situation X than in situation Y if the distance between conceptualizations built in X is less than the distance between conceptualizations in Y.

Method of deriving conceptualization	Average distance from helicopter built first to eggbeater built second (H1 - E2)	Average distance from eggbeater built first to helicopter built second (E1 - H2)
(1)	56.4	59.2
(2a)	55.9	62.8
(2b)	61.5	68.1

The helicopter (with 54 pieces and 58 connections) can be viewed as a simpler object than the eggbeater (60 pieces and 70 connections). It appears that the conceptualizations from H1 and E2 are somewhat closer together than those from E1 to H2. (No statistics have been performed.) A tentative conclusion is that there is more transfer (as measured by similarity of structure) from a simple to a complex object than from a complex to a simple one. If the result holds up with further analysis, it is easy to interpret theoretically. Presumably a more complex object has a more complex (deeper) structure. If it is practiced first and a part of the complex structure occurs in a simpler structure later (the case of E1-H2), a person may not be able to locate the part in the earlier structure because it is so deep in the hierarchy. Thus, very little transfer. In the case of simple first, complex second (H1-E2), more transfer is evident because the person has less difficulty locating the common part in the simple (shallower) structure and using it later. These comments are tentative; further data analysis is needed.

E. Empirical investigation of adequacy of knowledge representation for repair in a computerized tutor.

One goal of this project was to specify what should be the content of interactive instructions for repair. A subgoal was to specify what knowledge representation(s) of the object to be repaired should be in the program. We investigated what knowledge to include by collecting repair data as follows.

Subjects were asked to repair two malfunctioning objects, a flashlight and an unusual object made from the Capsela 1000 kit. Each subject had available a helper who had some knowledge which might aid in doing the repair. In the case of the flashlight, the knowledge came from the fictitious adult conceptualization of the flashlight given in the addendum to the proposal Principles of Instruction for Successful Maintenance and Repair. In the case of the second object, a similar conceptualization, consisting of nodes representing actions, visual concepts, names, and abstract concepts, was created and used. Using only the knowledge represented in these conceptualizations, the helper answered the subject's questions, either verbally or by demonstrating actions which were within the helper's conceptualization. If the subject requested information not in the representation, the helper responded, "I don't know."

The subject questioned the helper and performed actions on the objects until they were repaired. The helper recorded the actions and requests of the subject. The sessions were tape-recorded; a few were videotaped.

At the Tucson conference (1984) we presented the hypothetical multimedia conceptualization of a flashlight mentioned above. It is the specific

conceptualization that our expert helper pretended to have, in our repair experiment. We showed how to interpret a subject's actions while performing a repair according to this written-down conceptualization:

The actions of the subject as observed by the experimenter must be matched with the nodes of the graph as written. This is a direct use of the representation. The result is a traversal of the nodes of the concept. Using the performance of a specific subject doing a repair, we traced her conceptual walk on our graph. To get the subject's hypothetical partial conceptualization, we take all nodes visited by the subject and close them upward by the subconcept relation, to make a complete graph. The more tasks the subject performs, the better the graph we get.

One can iterate this process, comparing the graph of the helper and the subject, and adding new subjects, until nothing has to be added to the helper's concept. One can then drop from the conceptualization all nodes that are never used. The resulting graph can be used as a basic data structure for a computerized helper. (Some modifications of the graph could be done at run time, as we showed in the Tucson talk.)

The knowledge representation is also a tool for the following problem: The experimenter observes the subject and tries to analyze what went on. The final product of the analysis is often confused. Here, we start with our (objective) conceptualization. When we score the subject, all we have to do is mark nodes on a graph. So we see it as a workable way to do complex data analysis for complex situations, including motoric ones and interactions with the experimenter.

Finally, in experimental work, we examined an actual repair situation (on an object from the Capsela kit) and showed how some aspects of our planned program/subject interactions would be carried out. We were even able to show that, with a properly prepared graph structure, the program will outperform an expert helper in giving advice.

Final Remarks:

We summarize several findings from the project:

1. We have an easy-to-follow blueprint for the visual presentation of instructional material. Novices perform as well as more experienced people when given instructions so designed.
2. We suggest a multiple naming schema for unfamiliar parts which have two or more functions. Names should be constructed based on generic concepts, and extended for specific uses.
3. We have given seven guidelines for designing narration for video and film instruction.
4. For good transfer of learning, tasks should be ordered with simple ones early and more complex ones later.
5. We have a multimedia knowledge representation whose implementation looks promising as a data structure for an intelligent tutor to help with assembly and repair tasks.

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Table 1

Number of correct connections and proportion functional in assembly from memory. Table a presents results after viewing the tree-transformed videotape, T'. Table b contains results after viewing videotape T.

	average number of correct connections	proportion functional	average time to work (in minutes)	average number of pieces used	number of engineering majors
males (16 subjects)	49.4	9/16	70.8	76.8	1
females (16 subjects)	51.9	8/16	59.1	70.1	0

a. "tree-transformed" videotape, T'

males (16 subjects)	52.6	15/16	59.4	78.6	3
females (13 subjects)	37.2	4/13	64.6	65.5	1

b. videotape T

Table 2. Most commonly generated name for pieces.

piece number	most commonly generated name				
	<u>1</u>	<u>2</u>	<u>GROUP</u> <u>3</u>	<u>4</u>	<u>5</u>
12	wrench	small connector	propeller	propeller	small bar
13	wrench	large connector	propeller	propeller	propeller

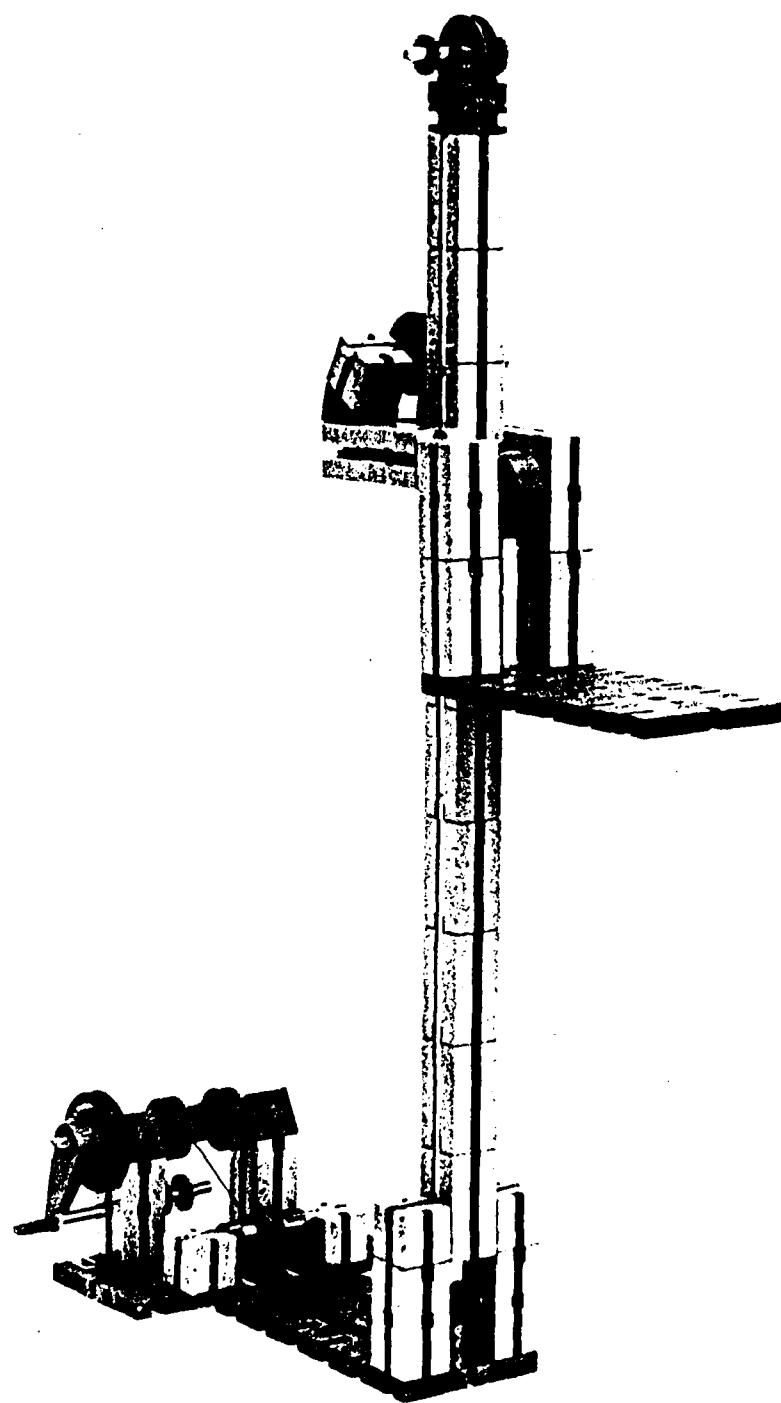


Figure 1

The 80-piece lift, built from the Fischer-Technik assembly kit.

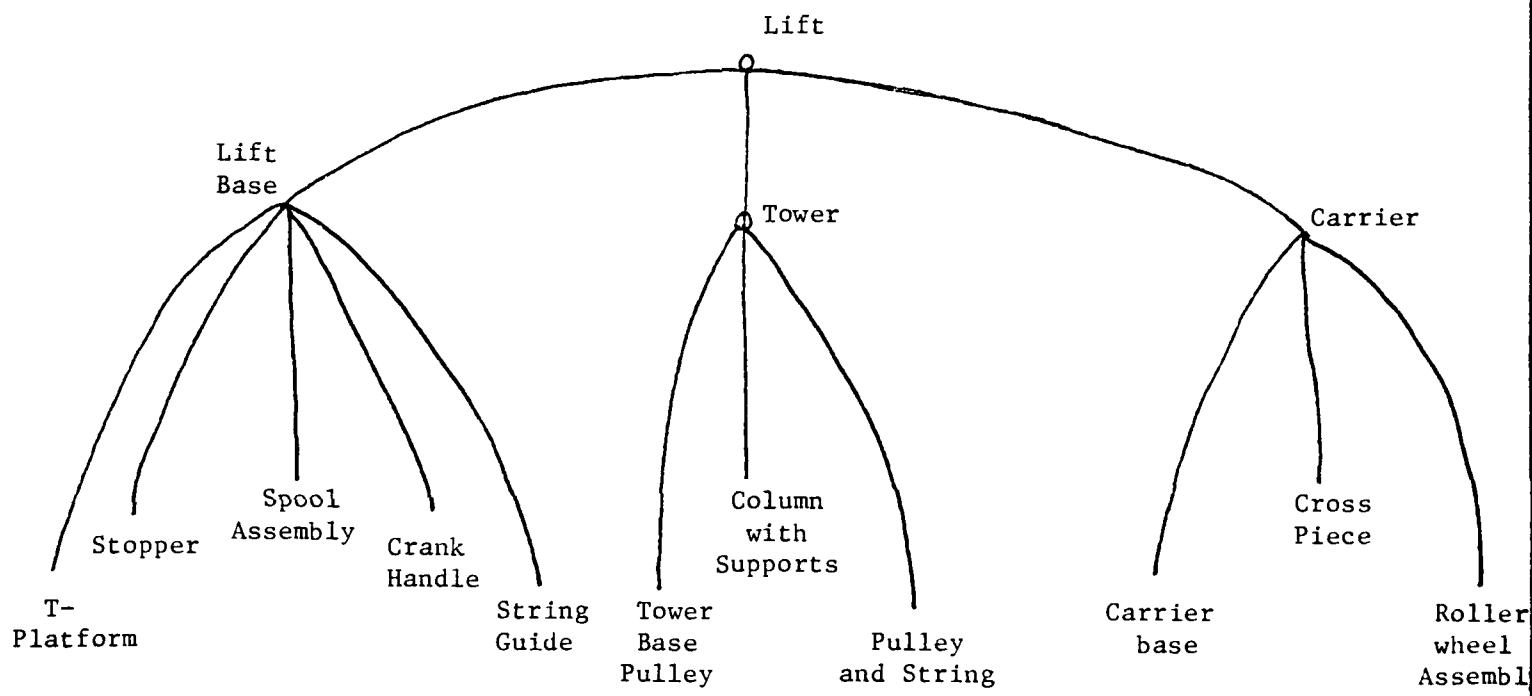
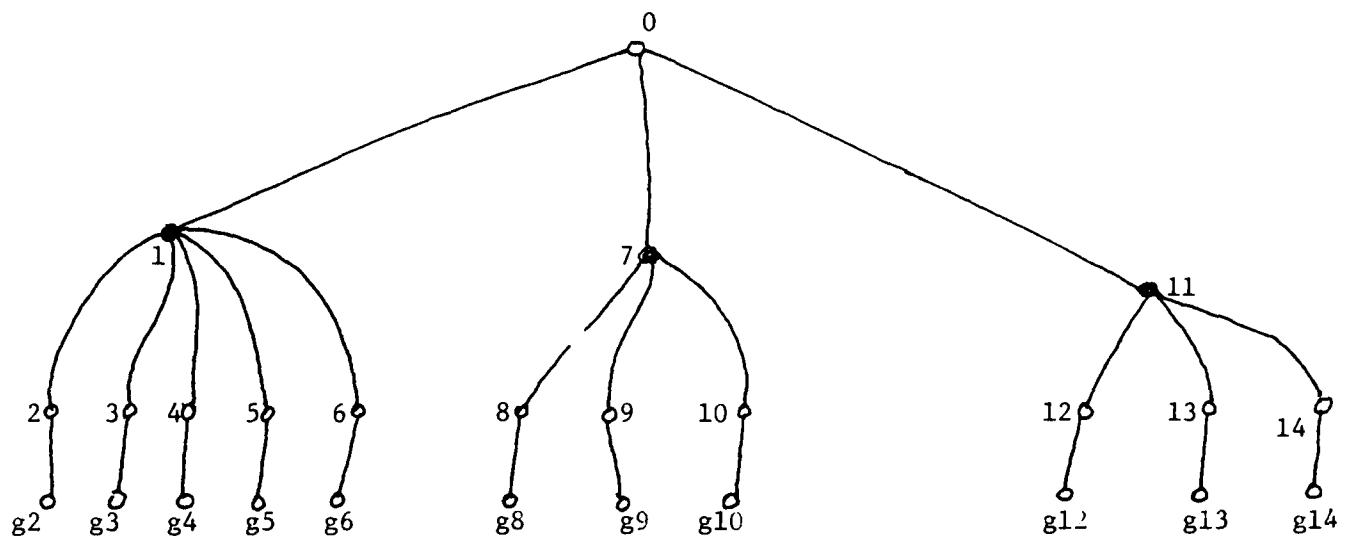


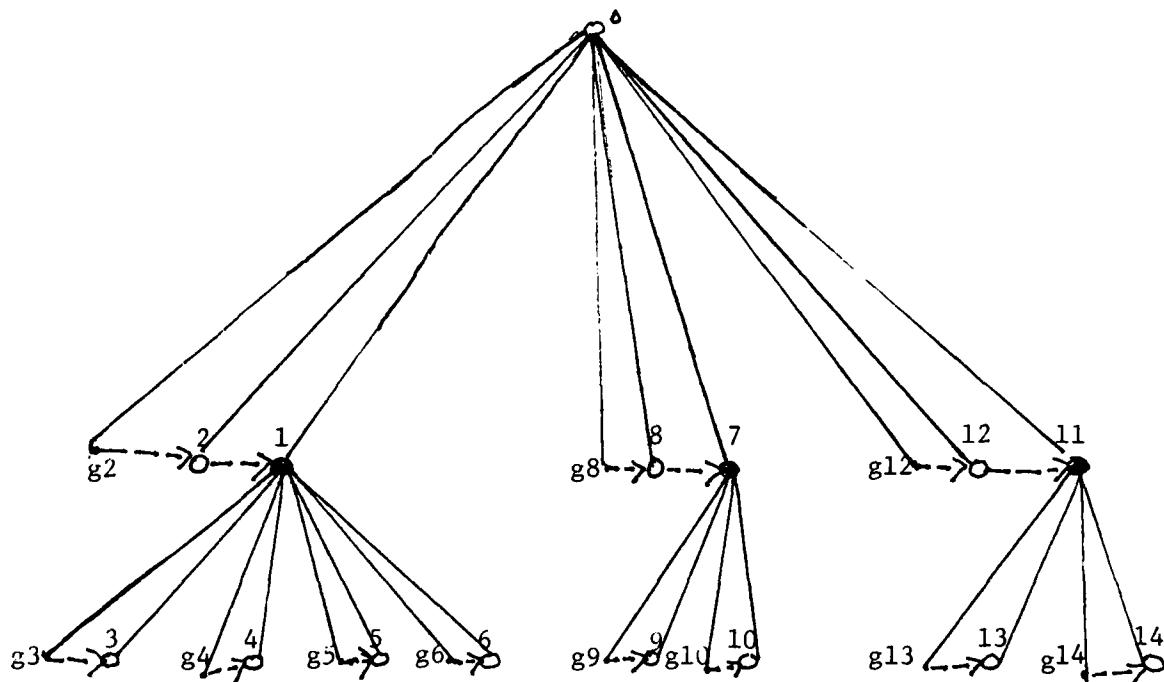
Figure 2



"g" means get pieces for a subassembly.

The goal of the structure is top-down; actions go the other way.

Tree T



-----> indicates prompting.

The subassembly at the head of each arrow is prompted by the item at the foot (left) of the arrow.

Tree T'

Figure 3

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